

FAULT TREES

Fault trees graphically illustrate the interaction among various system component failures (represented by basic events) and how they can lead to a failure of the system. This system failure, often referred to as the TOP event because of its location at the top of the particular fault tree, can occur if the appropriate combinations of basic events (identified as circles or diamonds) occur. The fault tree models on the following pages represent the basic event failures that must occur to cause a propulsion or steering system to fail.

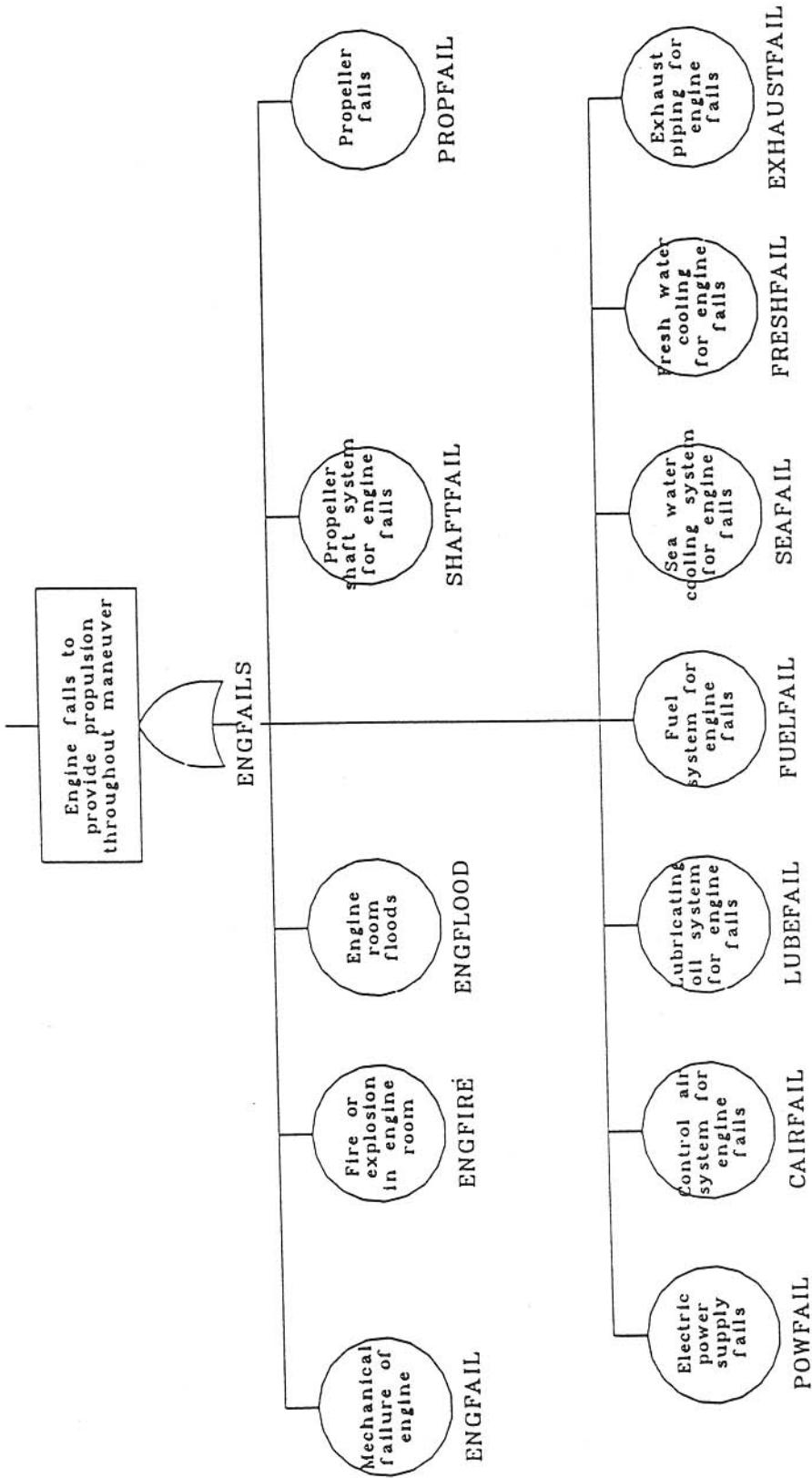


Figure A-1 Fault Tree for Failure of the Propulsion System on a Single Engine Tanker

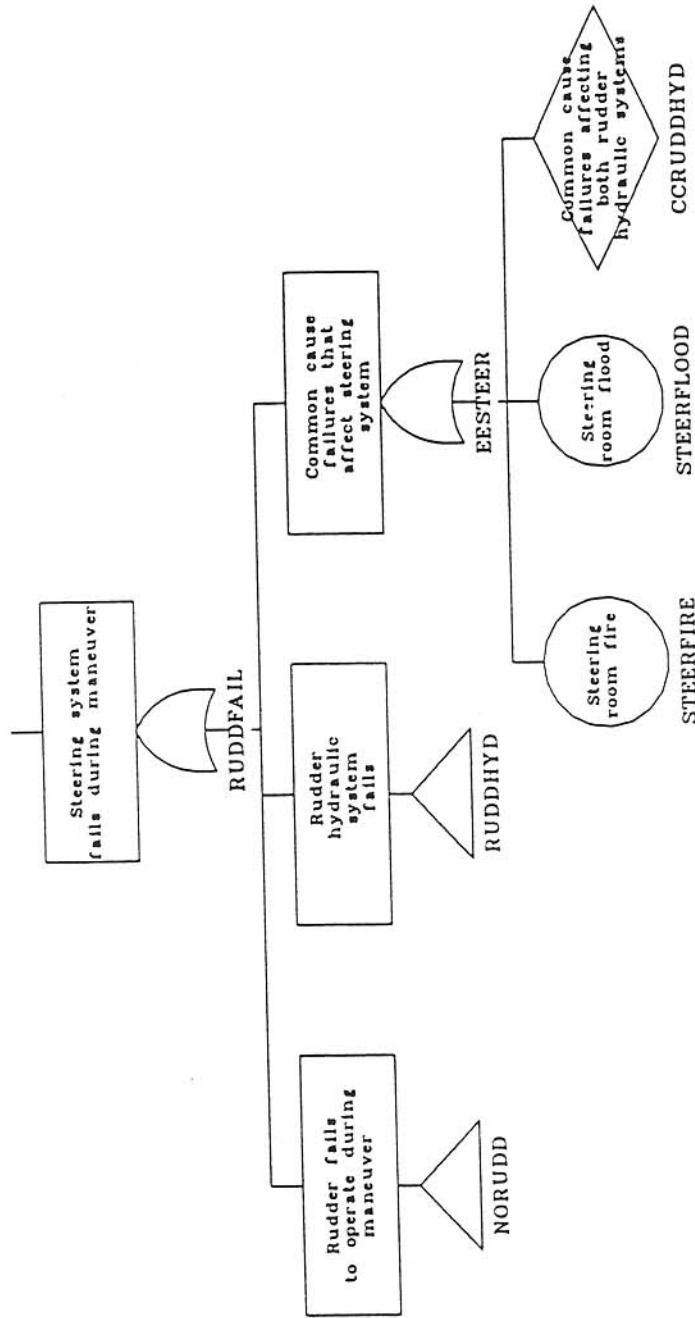


Figure A-2 Fault Tree for Failure of the Steering System on a Single Rudder Tanker

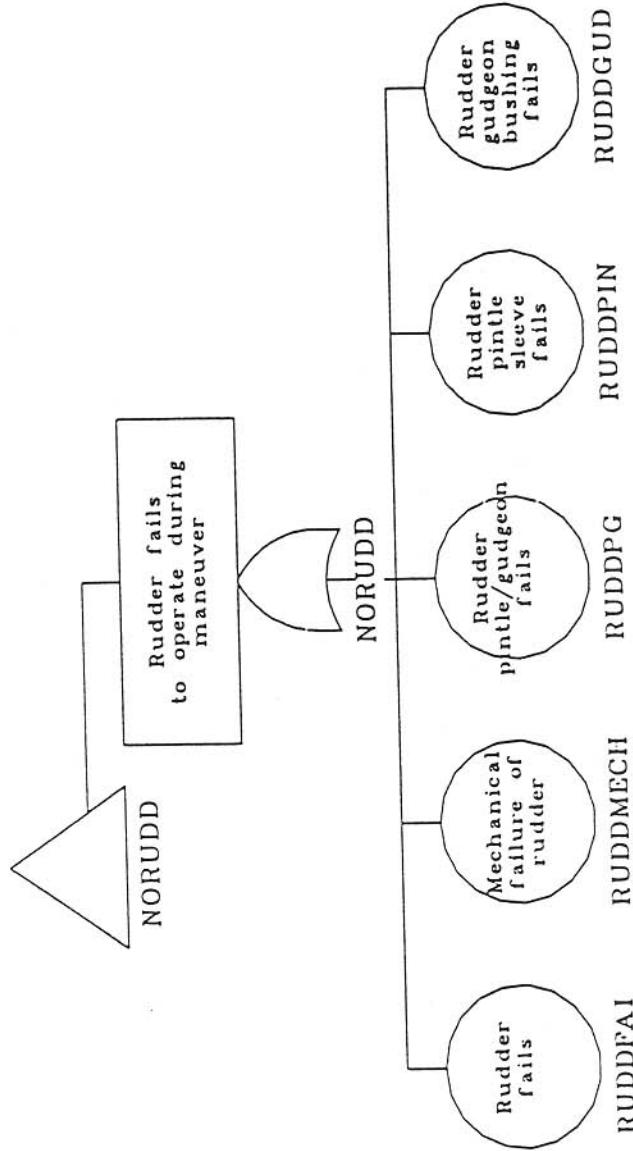


Figure A-2 Fault Tree for Failure of the Steering System on a Single Rudder Tanker (cont'd)

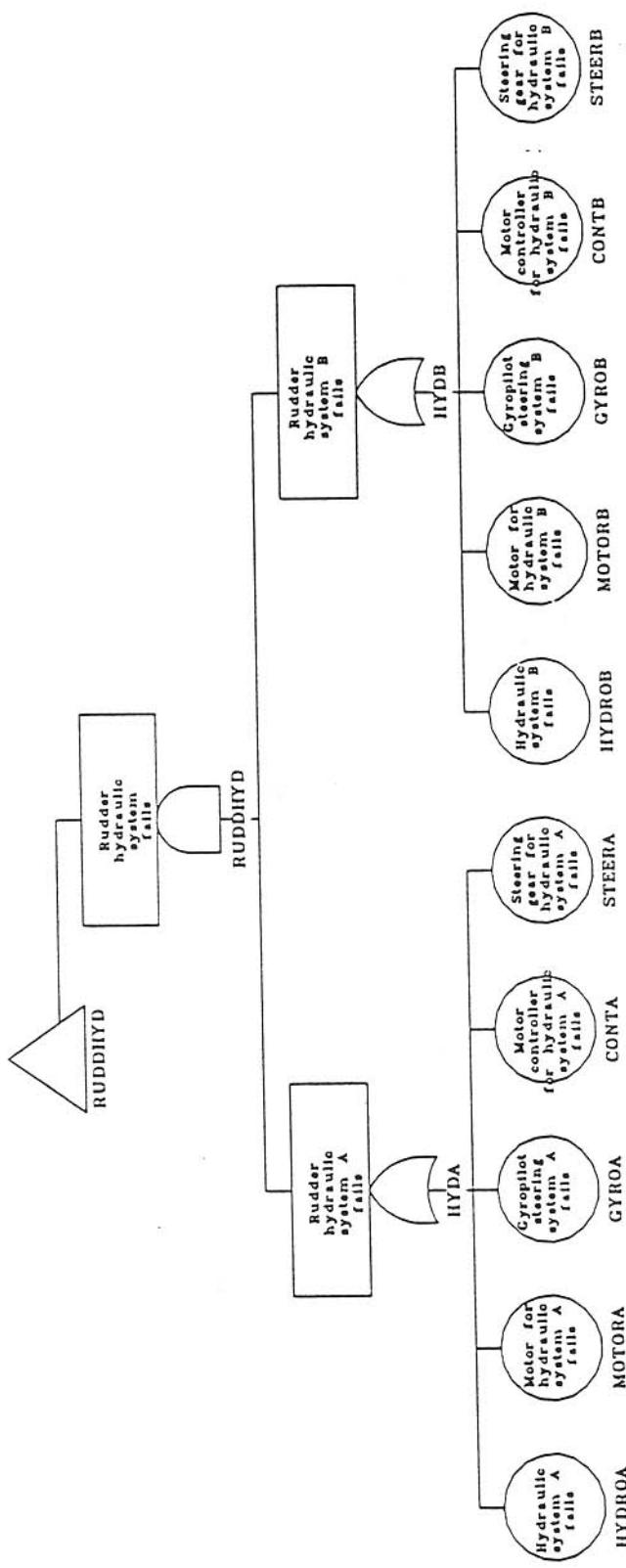


Figure A-2 Fault Tree for Failure of the Steering System on a Single Rudder Tanker (cont'd)

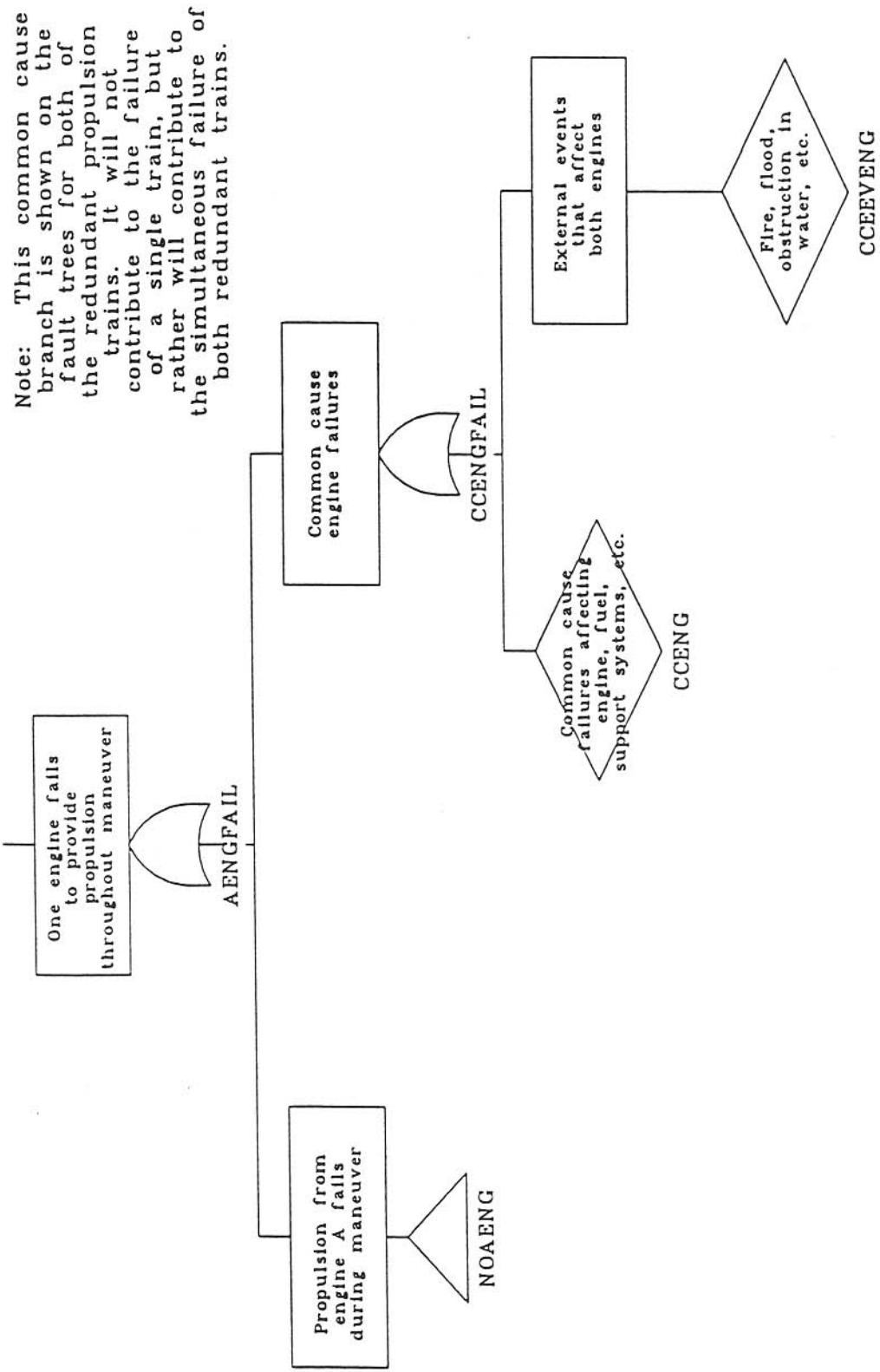


Figure A-3 Fault Tree for Failure of One Propulsion System on a Twin Engine Tanker

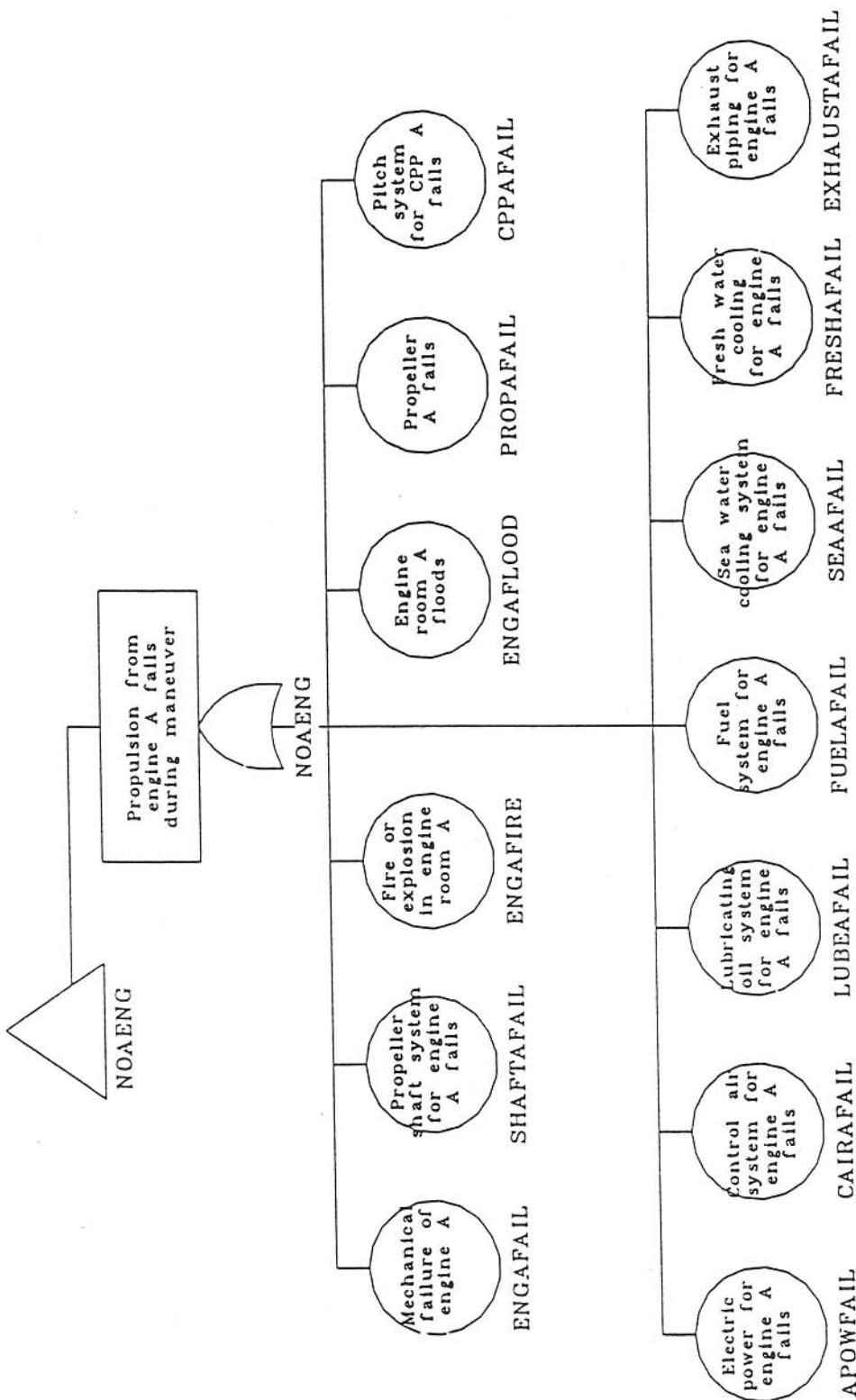


Figure A-3 Fault Tree for Failure of One Propulsion System on a Twin Engine Tanker (cont'd)

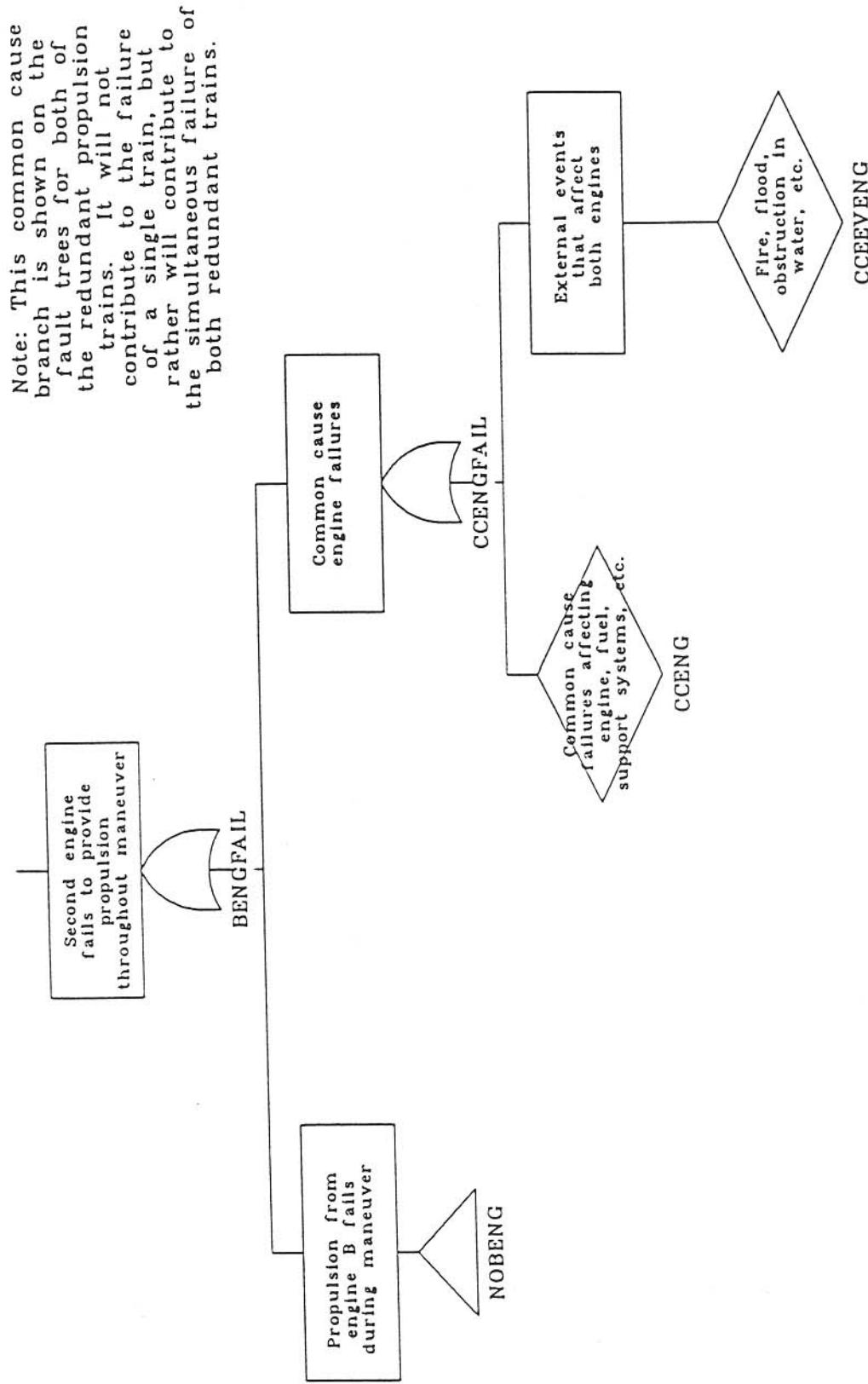


Figure A-4 Fault Tree for Failure of the Second Propulsion System on a Twin Engine Tanker

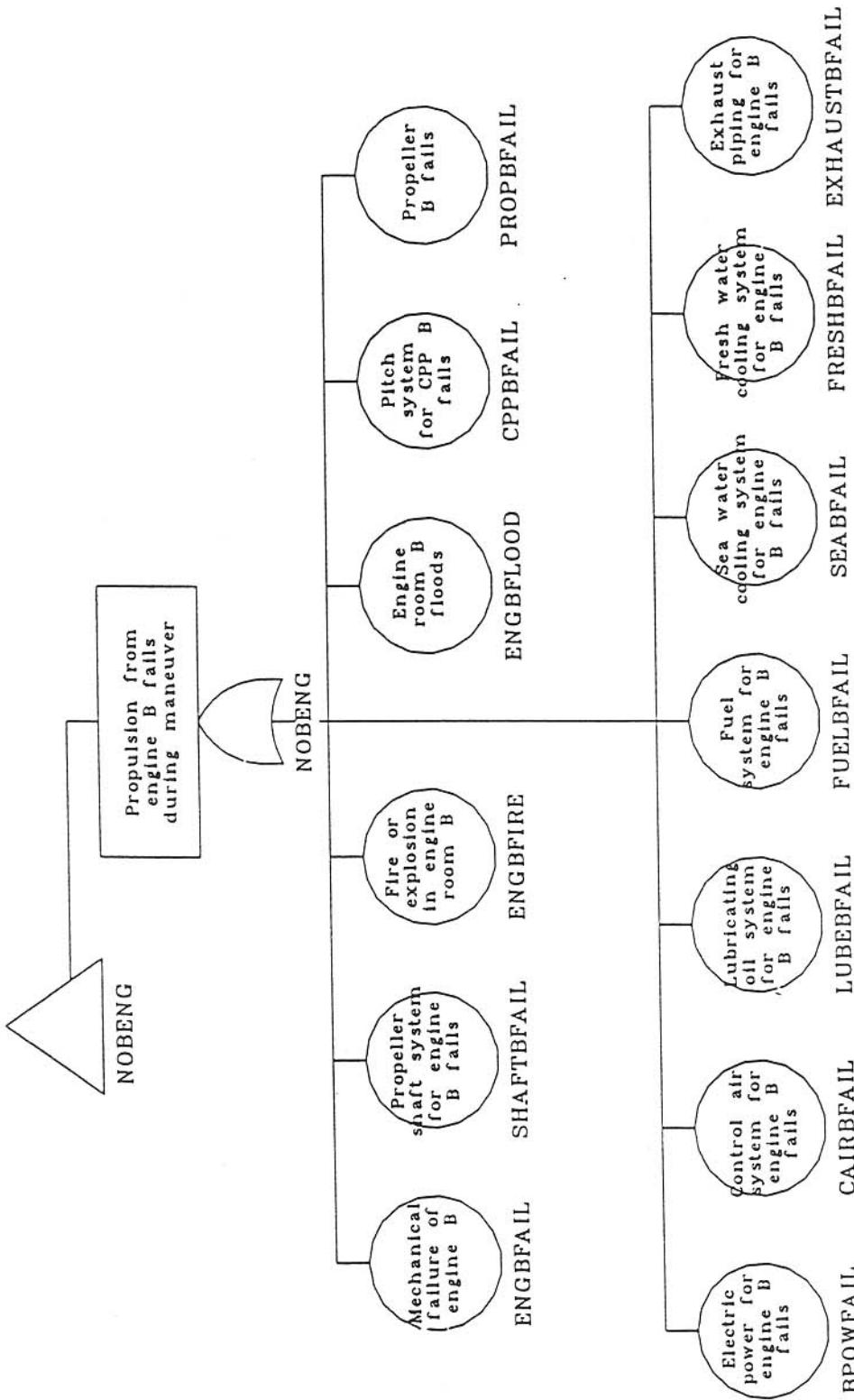


Figure A-4 Fault Tree for Failure of the Second Propulsion System on a Twin Engine Tanker (cont'd)

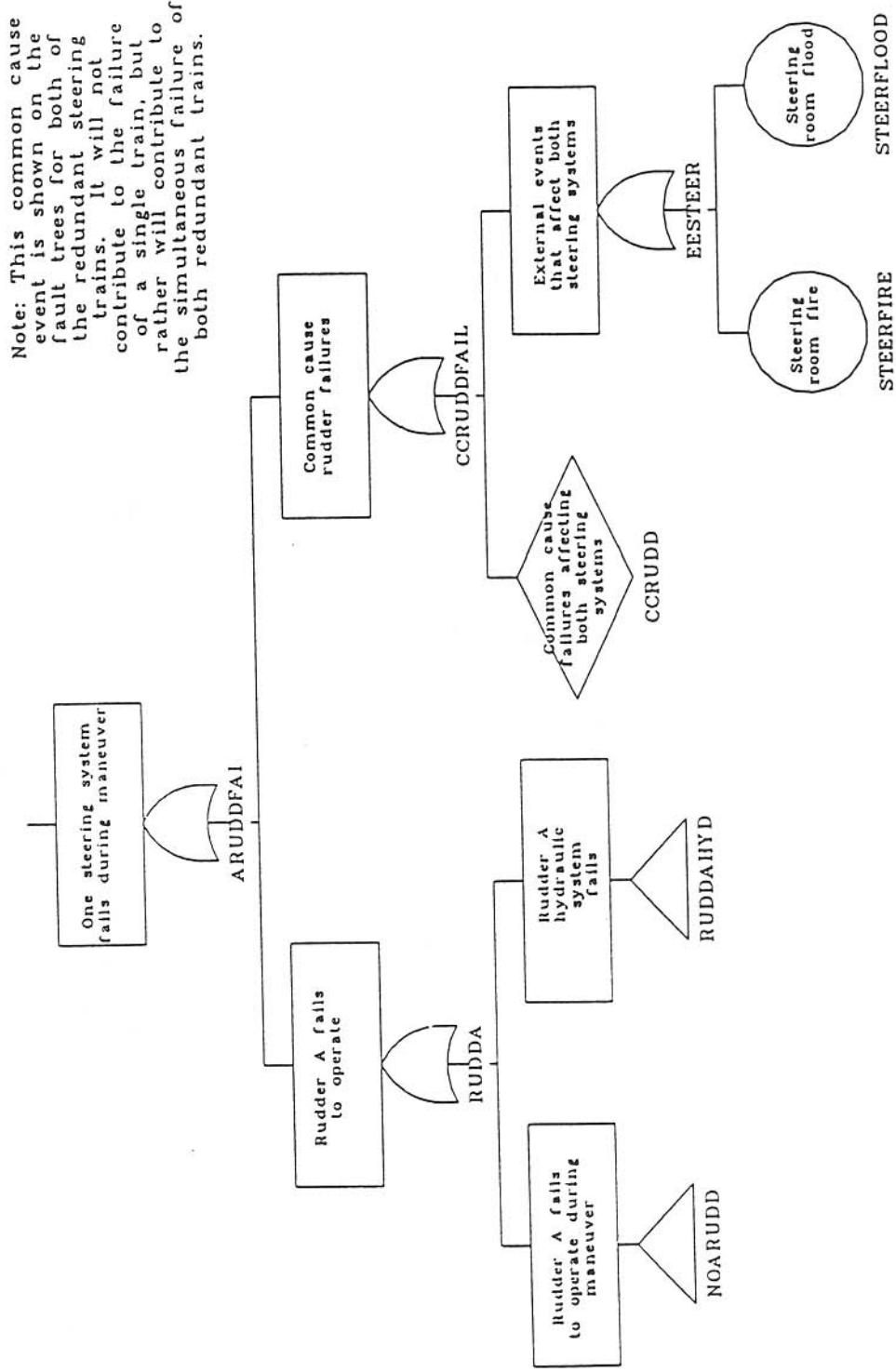


Figure A-5 Fault Tree for Failure of One Steering System on a Twin Rudder Tanker

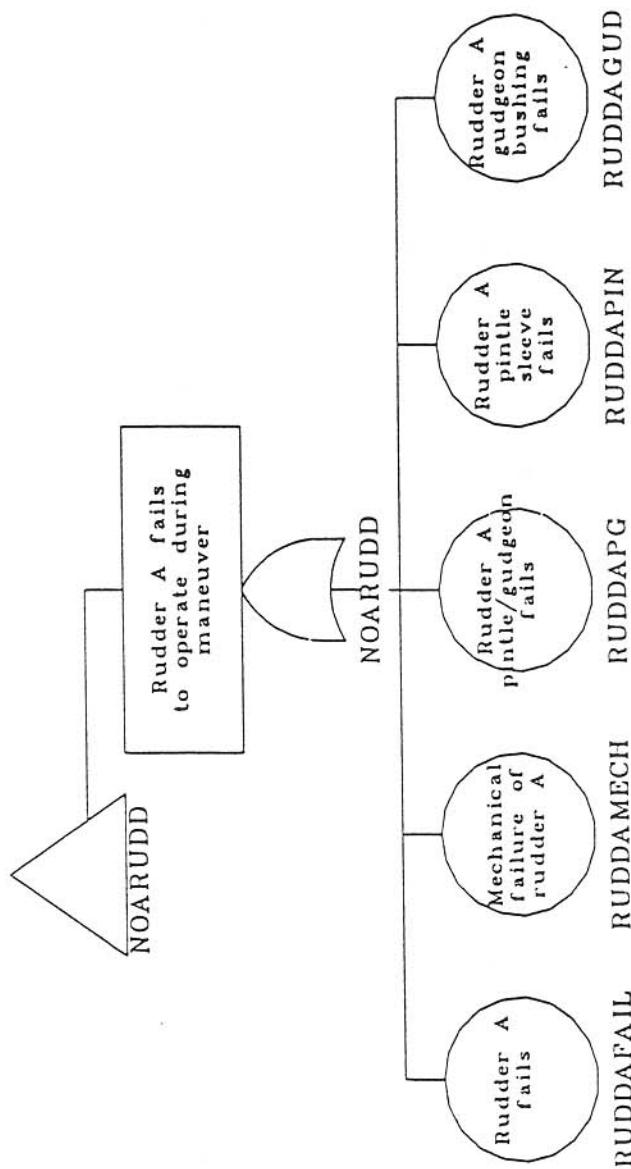


Figure A-5 Fault Tree for Failure of One Steering System on a Twin Rudder Tanker (cont'd)

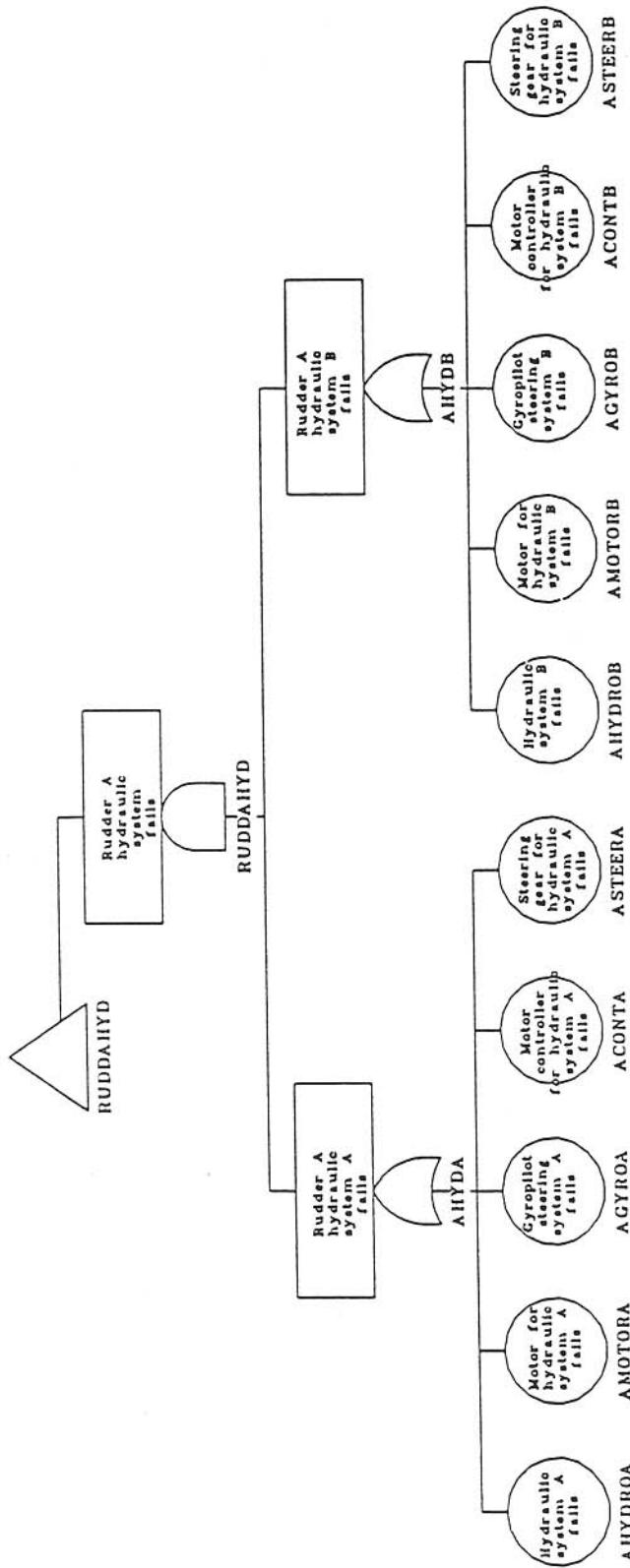


Figure A-5 Fault Tree for Failure of One Steering System on a Twin Rudder Tanker (cont'd)

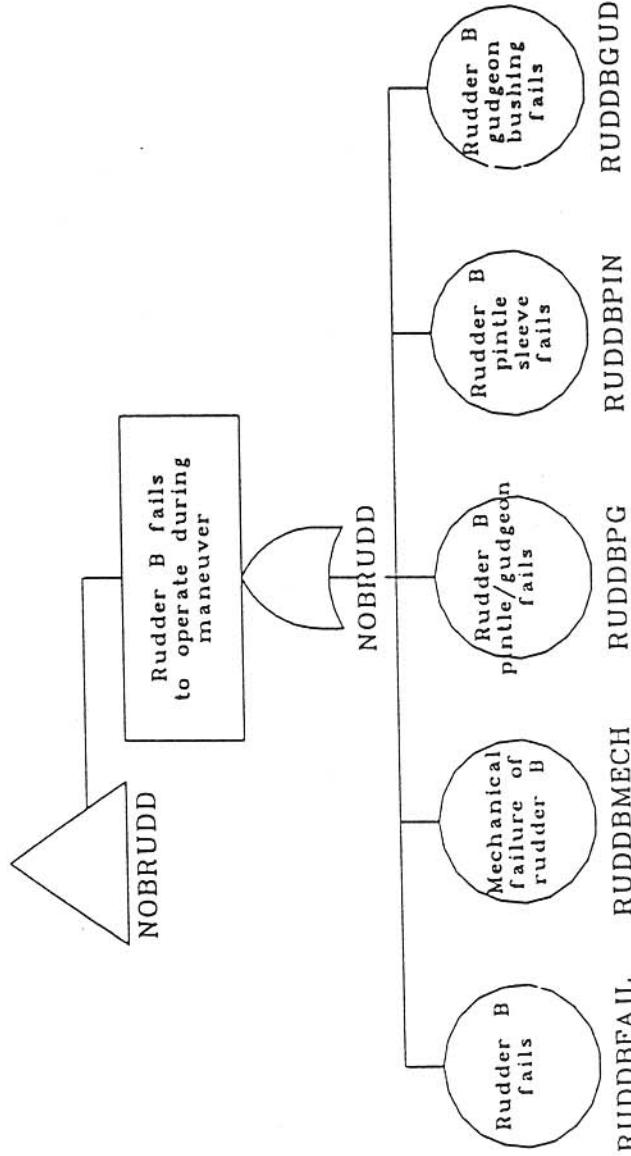


Figure A-6 Fault Tree for Failure of the Second Steering System on a Twin Rudder Tanker (cont'd)

Table A-1 Data Used in the Risk Assessment of the Effect of Redundancy in Propulsion and Steering Systems

Basic Event Name	Basic Event Description	Comments	Failure Rate (λ)(hr ⁻¹) or Probability (P) that the component fails sometime during the 8-hour transit	Reference
CCENG	Common cause failures affecting both engines	Assumed three beta factors, 0.05, 0.1, and 0.15, for this analysis. Values used in the fault tree are the product of beta times the system failure for a single engine (i.e., Gate NOAENG in the fault tree).	$P = 8.1 \times 10^{-4}$ $P = 1.6 \times 10^{-3}$ $P = 2.4 \times 10^{-3}$	
CCEEVENG	Fire, flood, obstruction in water, etc.	Analysis did not address external events such as obstructions in the water. Because the engines are in separate, fireproof, watertight rooms, the likelihood of a fire or flood affecting both engines was considered negligible.	ϵ	
ENGFAIL/ ENGBFAIL/ ENGBFAIL	Mechanical failure of engine	Used “Total System” failure rate from Table 8, source 1 in this reference.	$\lambda = 9.9 \times 10^{-4}$	2
ENGAFIRE/ ENGBFIRE/ ENGFIRE	Fire or explosion in engine room	Used one explosion occurrence from this reference and conservatively assumed one fire (since reference shows no fires) in 4,105 vessel transits.	$P = 4.9 \times 10^{-4}$	1
ENGAFLOOD/ ENGBFLOOD/ ENGFLLOOD	Engine room floods	Reference shows two “vessel integrity” failures in 4,105 transits. Analysis assumes 10% of these affect the engine rooms.	$P = 4.9 \times 10^{-5}$	1

Table A-1 Data Used in the Risk Assessment of the Effect of Redundancy in Propulsion and Steering Systems (cont'd)

Basic Event Name	Basic Event Description	Comments	Failure Rate (λ)(hr $^{-1}$) or Probability (P) that the component fails sometime during the 8-hour transit	Reference
APOWFAIL/ BPOWFAIL/ POWFAIL	Electric power supply for engine fails	Detailed analyses of the electric power systems were not performed. The vessels have multiple generators for supporting operation of the diesel engines, resulting in a very low overall system failure rate for electric power. This analysis conservatively assumes a failure rate for the electric power system that is based on the failure rate of the fuel supply system for typical oil tanker electric generators (from Table 1 in this reference). It is assumed that this value also accounts for common cause failures within the electric power system.	$\lambda = 2.2 \times 10^{-4}$	2
CAIRFAIL/ CAIRBFAIL/ CAIRFAIL	Control air system for engine fails	Used “Total System” failure rate from Table 3, source 1 in this reference.	$\lambda = 1.5 \times 10^{-6}$	2
LUBEFAIL/ LUBEBFAIL/ LUBEFAIL	Lubricating oil system for engine fails	Used “Total System” failure rate from Table 4, source 1 in this reference.	$\lambda = 8.8 \times 10^{-5}$	2
FUELFAIL/ FUELBFAIL/ FUELFAIL	Fuel system for engine fails	Used “Total System” failure rate from Table 5, source 1 in this reference.	$\lambda = 2.1 \times 10^{-4}$	2

Table A-1 Data Used in the Risk Assessment of the Effect of Redundancy in Propulsion and Steering Systems (cont'd)

Basic Event Name	Basic Event Description	Comments	Failure Rate (λ)(hr ⁻¹) or Probability (P) that the component fails sometime during the 8-hour transit	Reference
SEAFAIL/ SEABFAIL/ SEAFAIL	Sea water cooling system for engine fails	Used "Total System" failure rate from Table 6, source 1 in this reference.	$\lambda = 2.7 \times 10^{-4}$	2
FRESHFAIL/ FRESHBFAIL/ FRESHFAIL	Fresh water cooling for engine fails	Used "Total System" failure rate from Table 7, source 1 in this reference.	$\lambda = 5.3 \times 10^{-5}$	2
EXHAUSTAFAIL/ EXHAUSTBFAIL/ EXHAUSTFAIL	Exhaust piping for engine fails	Used "Exhaust Gas Piping" from Table 10, source 1 in this reference.	$\lambda = 8.3 \times 10^{-5}$	2
CCRUD	Common cause errors affecting rudder systems	Assumed three beta factors, 0.05, 0.1, and 0.15, for this analysis. Values used in the fault tree are the product of beta times the system failure for a single rudder (i.e., Gate RUDDA in the fault tree).	$P = 2.3 \times 10^{-5}$ $P = 4.6 \times 10^{-5}$ $P = 6.9 \times 10^{-5}$	
RUDDAFAIL/ RUDDBFAIL/ RUDDFAI	Rudder fails	Used "Rudder (General)" mean time between failures from Table 1.6 of this reference to calculate the failure rate.	$\lambda = 1.0 \times 10^{-5}$	3
RUDDAMECH/ RUDDBMECH/ RUDDMECH	Mechanical failure of rudder	Used "Rudder Structure" mean time between failures from Table 1.6 of this reference to calculate the failure rate.	$\lambda = 1.6 \times 10^{-5}$	3

Table A-1 Data Used in the Risk Assessment of the Effect of Redundancy in Propulsion and Steering Systems (cont'd)

Basic Event Name	Basic Event Description	Comments	Failure Rate (λ)(hr $^{-1}$) or Probability (P) that the component fails sometime during the 8-hour transit	Reference
AGYROA/ BGYROA/ AGYROB/ BGYROB/ GYROA/ GYROB	Gyropilot steering system A/B fails	Used "Gyropilot Steering" mean time between failures from Table 1.6 of this reference to calculate the failure rate.	$\lambda = 9.8 \times 10^{-6}$	3
ACONTA/ BCONTA/ ACONTB/ BCONTB/ CONTA/ CONTB	Motor controller for hydraulic system A/B fails	Used "Electric Motor Controller" mean time between failures from Table 1.6 of this reference to calculate the failure rate.	$\lambda = 1.2 \times 10^{-5}$	3
ASTEERA/ BSTEERA/ ASTEERB/ BSTEERB/ STEERA/ STEERB	Steering gear for hydraulic system A/B fails	Used "Steering Gear (General)" mean time between failures from Table 1.6 of this reference to calculate the failure rate.	$\lambda = 1.5 \times 10^{-5}$	3
STEERFIRE	Steering room fire	The probability of a fire in the steering room was assumed to be the same as that in an engine room.	$P = 4.9 \times 10^{-4}$	1
STEERLOOD	Steering room flood	The probability of a steering room flood was assumed to be negligible.	ϵ	

Table A-1 Data Used in the Risk Assessment of the Effect of Redundancy in Propulsion and Steering Systems (cont'd)

Basic Event Name	Basic Event Description	Comments	Failure Rate (λ)(hr $^{-1}$) or Probability (P) that the component fails sometime during the 8-hour transit	Reference
CCRUDH1YD	Common cause failure of the rudder hydraulic system tree).	Assumed to be 0.1 times the failure of one hydraulic system (Gate HYDA in the fault tree).	$P = 4.9 \times 10^{-5}$	